The COMPASS Broadband Trials

Trent R. Nanke
Barton G. Prieve

This paper describes AT&T Network Systems broadband trials, their objectives, technologies, services, applications, and results for each. The five U S WEST COMPASS trial projects were conducted in the areas of narrowband Integrated Services Digital Network (ISDN), executive desk-top videophone, switched digital signal level 1 (DS1), Switched Multimegabit Data Service (SMDS), and broadband ISDN (BISDN)/asynchronous transfer mode (ATM). We emphasize what has been learned from these trials about broadband technologies, services, and applications.

Introduction

In early 1991, AT&T Network Systems, U S WEST, and two other switch vendors began a three-year program to test various aspects of broadband communication. U S WEST anticipated the need to gain an understanding of the applications, markets, and technologies associated with high-speed communications. Although it would be several years before BISDN prototype systems would be available for trials, the Communications Program for Advanced Switching Services (COMPASS) was structured to allow immediate trial activities to test markets and applications using available technologies. (See Panel 1 for definitions of abbreviations, acronyms, and terms.) Final trial activities would use a BISDN/ATM prototype system to test two applications. AT&T played a critical role in each of the five-step series of trials. This paper presents an overview of the COMPASS program, AT&T's role in each trial, and the results obtained from its participation. The first four projects are described briefly, and the final project is discussed in detail.

Background

Simply stated, the mission of COMPASS was: ***To understand customer broadband application needs and to define equipment and service requirements to meet those needs.*** Potential applications were classified in four general categories:

- Video — Educational, interactive, and desk-top;
- High-speed image transfer — Business graphics, medical imaging, scientific visualization, and computer-aided design, manufacture, and engineering (CAD/CAM/CAE);
- Computer networking — Host-to-host, and local area network (LAN) bridging; and
- Multimedia access — Integrated workstations supporting video, voice, data, and image simultaneously.

Because no true broadband (155 megabits per second, or Mbits/s) switching equipment would be available for trials until 1993, the COMPASS program began using available technologies to test applications as early as 1991. Five trial projects were designed: high-speed data networking (using narrowband ISDN), executive desk-top videophone, switched DS1 (also known as DS1 Dialtone), SMDS (later expanded to include frame relay), and BISDN/ATM (see Table I).

AT&T supported all five trials. The activities and information gained as a result of each trial are described as follows.

Project 1 - High-Speed Data Networking

The first application that AT&T tested with U S WEST was electronic image acquisition and delivery. Users included MBA students and their instructors at the Carlson School of Management, part of the University of Minnesota. Images were stored in an IBM AS/400 computer and accessed by workstations connected to ISDN lines. No new switching equipment was required, because U S WEST had 5ESS® electronic switches with ISDN capability deployed in Minneapolis.

The users found this ISDN application extremely useful. Even at 64 kilobits per second (kbits/s), transmission times of images were satisfactory. Most of what was learned pertained to difficulties in supporting ISDN: ubiquity of service, price of service, support personnel and systems, and sales support. Although this trial was considered a success by its users, U S WEST rediscovered many of the same difficulties in supporting ISDN that had been found elsewhere.

Project 2 – Executive Desk-Top Videophone

Users in the second trial project were high-level executives within U S WEST. A group of users who talk to each other frequently were given a color Picturephone-style service.

The system was designed and developed based on a prototype ISDN switch. Special terminals that provided eye contact were also built. These "eye-to-eye" terminals used a system of mirrors to permit eye contact and provide life-size video. AT&T ISDN 7507 Display Terminals provided dialing, speed calling, audio, and call control features, all of which were based on voice calling. Split-screen, three-way calling (conferencing) was also included. Reference 1 contains more information about this trial system.

Two phases of this trial were run. In the first phase, 10 users in two cities (Denver and Minneapolis) were connected using 45-Mbit/s video lines. The second phase, which included 25 users distributed among five cities, used 384-kbit/s compressed video. Figure 1 depicts the network architecture.

We learned important information from this trial. In general, users in Phase 1 — which featured full motion, life-size, high-quality video with no perceptible delay, using 45-Mbit/s video transmission — reacted very positively. Ease of system use was important to them, as well as the eye-to-eye contact, which some stated was an absolute requirement. Having life-size video gave the users the feeling of being in the same room. The half-duplex audio was frequently mentioned as a negative aspect of the equipment, even more prevalently in Phase 2. Almost all executives used their ISDN 7507 speakerphones, rather than their handsets. Therefore, audio conversations were limited to what we have available in most office environments today. We concluded that when a new, high-quality video service is offered, today's standard of half-duplex speakerphone audio will no longer be acceptable to users.

Phase 1 system users wanted the ability to transfer documents or, at least, to support a separate document camera. Some users wanted their secretaries to be

Panel 1. Abbreviations, Acronyms, and Terms

ATM — asynchronous transfer mode
BISDN — broadband ISDN
BRI — basic rate interface (ISDN)
CAD — computer-aided design
CAE — computer-aided engineering
CAM — computer-aided manufacture
CBR — constant bit rate
COMPASS — Communications Program for Advanced Switching Services
CPE — customer premises equipment
CSU — channel service unit
DACS — Digital Access and Cross-Connect System
DS1 — digital signal level 1
DSU — digital service unit
FDDI — fiber distributed data interface
HSSI — high-speed serial interface
ISDN — Integrated Services Digital Network
kbit(s)/s — kilobit(s) per second
LAN — local area network
LEC — local-exchange carrier
Mbit(s)/s — megabit(s) per second
NTSC — National Television System Committee
OAM&P — operations, administration, maintenance, and provisioning
PRI — primary rate interface
PVC — permanent virtual circuit
SMDS — Switched Multimegabit Data Service
SONET — synchronous optical network
STS-3C — Synchronous Transport Signal, level 3 concatenated
SVC — switched virtual circuit
TA — terminal adapter
VBR — variable bit rate
VCI — virtual circuit identifier

Table I. AT&T/U S WEST COMPASS Projects

COMPASS Project	Timeframe	Technology	Speed	Applications			
				Image Delivery	Audio/Video Conferencing	LAN Interconnect	SONET/ATM Networking
1	4Q91–2Q92	Narrowband ISDN	64 kbits/s	√			
2	2Q91–1Q92	PRI, DS3	384 kbits/s, 45 Mbits/s		√		
3	4Q91–4Q92	DS1	1.5 Mbits/s	√	√		
4	4Q91–2Q92	SMDS, frame relay	≤ 45 Mbits/s	√		√	
5	3Q93–1Q94	BISDN/ATM	≤ 155 Mbits/s	√	√	√	√

able to answer their videophone calls. Finally, office lighting was discovered to be an unexpected, frequent difficulty, because cameras do not perform well in an environment with strong backlighting.

When compressed video was introduced, Phase 2 of the videophone trial uncovered the most significant problem. *Codecs*, which use signal compression and decompression techniques, inserted so much delay from the time one user spoke until the other user saw and heard the conversation that the service was deemed unacceptable. This occurred despite the fact that we provided lip synchronization by delaying the audio to match the video display. Even when tests were run with higher-speed codecs (up to 1.5 Mbits/s), the delays were perceived as unacceptable. Because all codecs complied with the H.261 teleconference standard,[2] this implied that highly compressed video, which is based on current teleconferencing standards, will probably never be acceptable to users who want to replace face-to-face conversations with videophone calls. H.261 may only be acceptable for desk-top video when it is an inexpensive addition to desk-top multimedia, in which the video is incidental to the communication.

Project 3 – Switched DS1

The concept behind Project 3 was to provide a service of dialable DS1 connections modeled after voice calling. Just as we can make voice calls today to virtually any phone, a switched DS1 user was able to call any other switched DS1 user. DS1 calls were set up using a standard ISDN set. Figure 2 shows a diagram of this trial.

Switched DS1 service enabled customers to transmit a medical image from several remote sites that had image acquisition equipment to a single central site where images were stored and used for diagnostics. Although the service was extremely reliable and worked as planned, this customer found the service unsatisfactory. Call setup times were comparable to voice-call setup time, but users found the extra step of dialing a connection objectionable because they were accustomed to dedicated T1 lines, which require no call setup. The other, far more serious, problem was that users would frequently forget to disconnect a call after completing their image transmissions. This caused other sites to encounter busy signals when trying to place a DS1 call to the central site.

These two major problems could be partially addressed by building all the call dialing and disconnect logic that transmitted the image into the computer software. But providing the telecommunications service alone is not sufficient to satisfy users. This customer later became a Project 4 (SMDS) user, and found that service entirely acceptable because, even though the effective transmission rate was lower than DS1, it operated more like a dedicated facility.

The second application test of switched DS1 was videoconferencing. For this application, which is characterized by calls with long holding time, the operational problems noted in the earlier application did not occur. Users equate setting up a videoconference call with setting up a voice conference, so the dialing mechanism was satisfactory. However, many videoconferencing users felt that a full DS1 of bandwidth would be too expensive for videoconferences, which usually are transmitted at 384 kbits/s. Therefore, customer demand reinforced the need for fractional T1 capability.

What we gained from the switched DS1 trial was the knowledge that switching a full T1 pipe was not, by

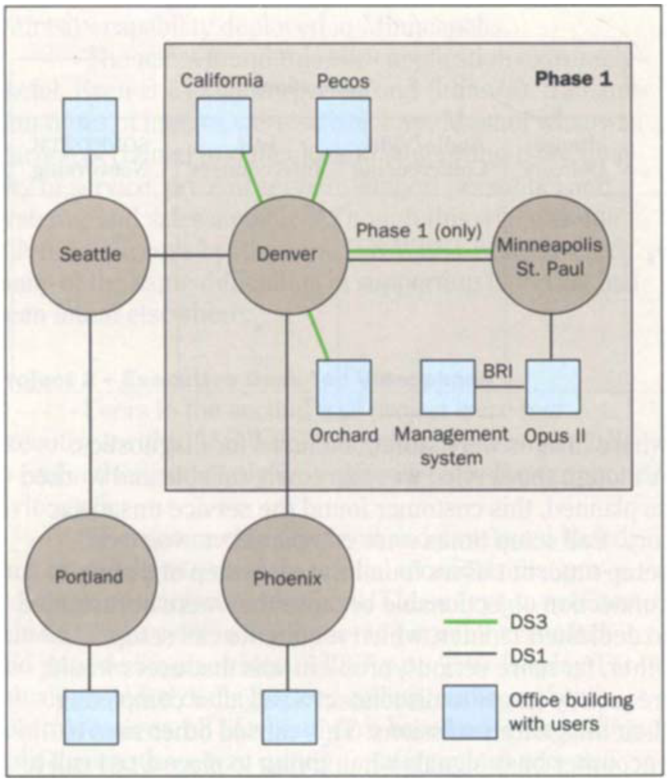


Figure 1. Project 2 — Executive desk-top videophone trial network. In phase 1, 10 users were supported in Denver and Minneapolis, using DS3 for video. In phase 2, 25 users in 5 cities were supported using 384-kbit/s compressed video.

itself, a viable service. Data users expect integrated, automatic call setup to simulate the operational ease of dedicated lines. Videoconferencing users want the full flexibility to dial up bandwidth at specific rates lower than the full DS1 rate. The availability of switched fractional T1 service (also known as n×DS0 switching) in the 5ESS switch has superceded the need for a separate, full T1 switching product.

Project 4 – SMDS and Frame Relay

The fourth COMPASS project involved supporting public network services for interconnecting LANs. Users on separate LANs wanted to be able to operate as if they were working on the same LAN. Two approaches to address this need have evolved in the data communications world: SMDS and frame relay. These two services were deployed for trial in COMPASS using AT&T's BNS-2000 high-speed data switch (see Figure 3). The BNS-2000 can accommodate both SMDS and frame relay services simultaneously in the same switch, so both services and multiple applications could be supported during the trial.

This trial was so successful that, before it was completed, U S WEST was convinced that a public offering of LAN interconnect data services should be made. During this trial, we observed that:

- Customer premises equipment (CPE) that interfaces with frame relay and SMDS worked satisfactorily with the BNS-2000
- SMDS provided an effective maximum throughput of 1.2 Mbits/s over T1 access
- Both frame relay and SMDS services could be viable for U S WEST.

As we noted in the discussion of Project 3, one user of switched DS1 trial service much preferred SMDS over switched DS1, because it was easy to use and appeared to be a dedicated facility.

Project 5 – Broadband ISDN/ATM

The intent of this project was to provide a flexible trial system that would demonstrate the benefits of ATM, explore broadband operations, administration, maintenance, and provisioning (OAM&P) issues, and test the marketability of BISDN services. We set out to:

- Demonstrate AT&T's commitment to broadband as a provider of current and future technology,
- Demonstrate the advantages of BISDN, specifically integration of services and overall flexibility,
- Provide a flexible ATM prototype platform to be used in the field to test the marketability of potential BISDN ATM-based applications and services,
- Identify customer needs that will drive the BISDN product technical service requirements and help the local-exchange carriers (LECs) formulate service tariffs,
- Gain a better understanding of how to manage a BISDN network (OAM&P),[3]
- Identify key issues associated with providing and provisioning ATM equipment, and
- Provide input to the evolving BISDN standards.

Applications, Capabilities, and Interfaces. To achieve our stated objectives, AT&T and U S WEST defined a set of desired capabilities for Project 5. The AT&T BISDN trial system supported the targeted end-user applications shown in Table II. The traffic of the targeted applications was characterized either as variable-

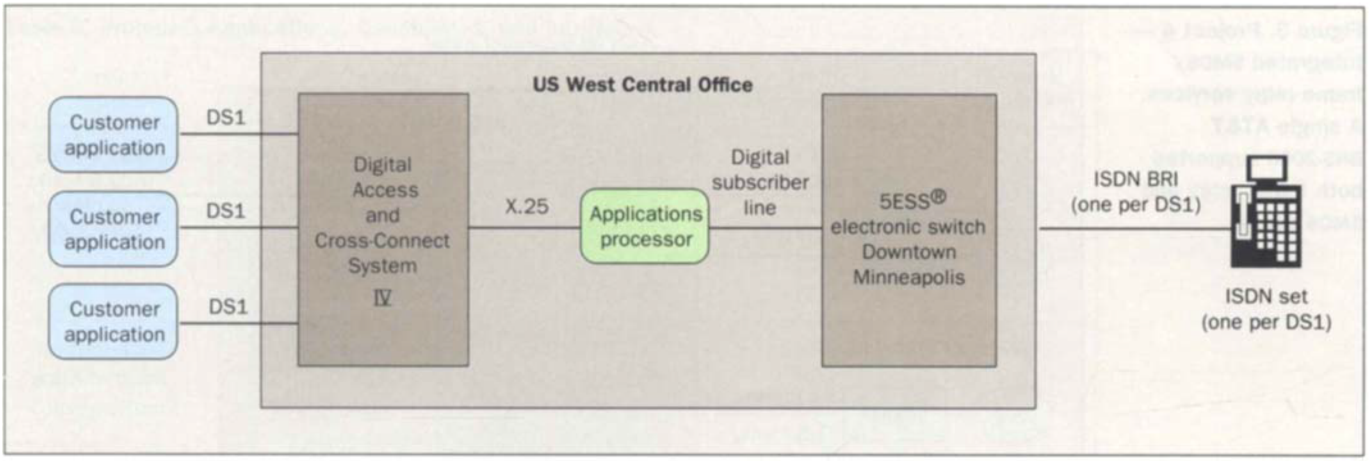


Figure 2. Project 3 — Switched DS1 trial architecture. AT&T's DACS-IV, controlled by a specially programmed applications processor, was used to supply switched DS1 service. Users initiated DS1 calls with a standard ISDN telephone set.

bit-rate (VBR) bursty data traffic, or constant-bit-rate (CBR) traffic. It was transmitted over connection-oriented virtual circuits that could be established as permanent virtual circuit (PVC) or switched virtual circuit (SVC) connections.

Voice and video conferencing capabilities were provided using commercially available video codecs and SVC circuit emulation with ATM. Multiple rates could be supported, including DS3 and DS1, and both point-to-point calling and conference (up to four parties) calling were available. Participants in a conference call could select either a split-screen view of all parties on the call, or a full-screen view of any one participant. A voice-activated audio system allowed any party to be heard without manual activation.

Voice and video conferencing incorporated a high-resolution graphics capability. The user could send screen images and files to other users. SMDS connectionless data service provided the graphics data transport for the multimedia service.

An SMDS connectionless data capability can support applications such as CAD/CAM/CAE, medical image networking, and LAN interconnect applications. In the BISDN trial system, this was provided by a connectionless service function in the BNS-2000 node and an SMDS terminal adapter at the customer premises. The SMDS connectionless service function in the BNS-2000 node terminated connectionless protocols and routed cells to a destination user according to routing information included in user cells. Connectionless data service between user interfaces was supported by connection-oriented virtual channels at the ATM layer, which were established between the user-network interfaces and the BNS-2000 connectionless server node.

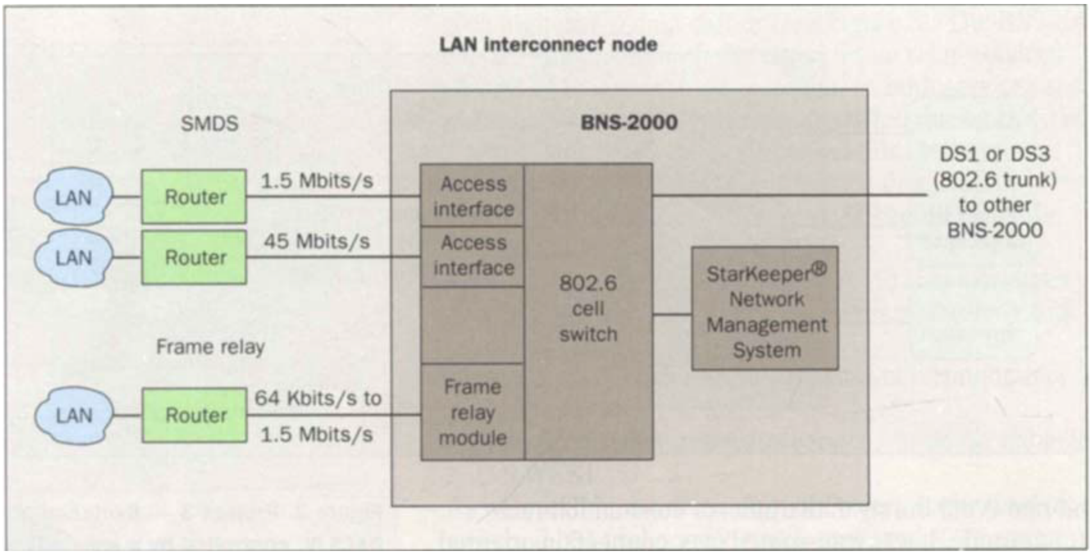
BNS-2000 interconnection was provided as a VBR service in which the DS3 SMDS-formatted ATM cells were translated into BISDN ATM cells to statistically multiplex them onto a synchronous optical network (SONET) link at the user network interface. A BNS-2000 source node could route VBR traffic across the BISDN trial system, over PVCs, to a destination BNS-2000 node.

The system emulated general CBR circuits, such as DS1 and DS3 private circuits, using either PVCs or SVCs. These circuits carried data, voice, or video information.

At the user network interface, the system connected SONET and ATM layers. This provided the potential of interworking with other vendors' equipment at these protocol levels.

High-Definition Distance Learning Application. The first application tested in Project 5 supported high-definition distance learning. The application created *virtual* classrooms for radiology interns rotating among three hospitals in Minneapolis. This teaching environment allowed lecturers to show high-resolution 35-millimeter slides, and X-ray and magnetic resonance imaging (MRI) scans; point and annotate during the lecture; see and hear students in the other two remote classrooms on monitors; and use an electronic whiteboard for drawing and writing. Interns could see high-

Figure 3. Project 4 — Integrated SMDS/ frame relay services. A single AT&T BNS-2000 supported both frame relay and SMDS users.



resolution images locally and remotely; enjoy high-quality, clear audio communication; interact with lecturers by speaking, pointing, or annotating; and feel as if they were all sitting in the same classroom.

Real-Time Manufacturing Process Control. The second application tested in Project 5 was a high-performance network that interconnected Honeywell's Sensor and System Development Center, the Minnesota Supercomputing Center, and the University of Minnesota Computing Department. The trial used a SONET/ATM real-time, priority-based control network to interconnect commercial ATM LAN hubs/switches at 155 Mbits/s, which is the optical carrier, level 3 (OC-3) rate. This application required appropriate traffic specification and support of traffic delivery based on deadlines defined by the user. The trial supported multiple PVCs with two levels of priority and a single physical SONET end-point. End-to-end delivery of sensor information was tested under different network conditions. To emulate various network conditions, traffic loads were generated from numerous sites, and performance data was collected.

System Architecture. Given the necessity to provide a flexible broadband platform when few broadband products were available, much of the hardware and software integrated into this system were prototypes.

The functionality of the system was partitioned among several interconnected subsystems (see Figure 4). These subsystems included the ATM switch, general terminal adapter, narrowband service module, node processor, support processor, video/audio bridge, BNS-2000 node, SMDS terminal adapter, and ISDN CPE.

ATM switch. The ATM switch interconnects the various general terminal adapters, and other SONET-based switches, by transporting and switching ATM cells on the basis of their virtual circuit identifiers (VCIs). The switch subsystem is a self-routing ATM cell switch that supports the 48+5 octet ATM cell format. The switch, which terminates the ATM layer protocol on a SONET Synchronous Transport Signal, level 3 concatenated (STS-3C) on each port, performs switching based on the VCI value. In addition, the switch provides a control interface to the support processor (SP) subsystem for OAM&P. The ATM switch is a prototype multistage alternate routing switch (MARS) three-stage Benes network.

General terminal adapter. Primarily, general terminal adapters adapt various standard interfaces to the BISDN user network interface, set up paths between line interfaces and the user network interface in response to signaling messages from the support processor, and provide some OAM&P functions in cooperation with the support processor. The general terminal adapters in the BISDN trial system support interfaces for DS1, DS3, DS3/802.6, basic rate interface, and SONET STS-3C.

Narrowband service module. The narrowband service module contains a local processor, a switch fabric entity, and service circuits that provide narrowband switching. Based on the prototype ISDN switch used in Project 2, the narrowband service module terminates and switches B

Table II. Project 5 Applications, Capabilities, and Interfaces

Customer need	System capability	Information type	Traffic characteristics	Network connection
Voice	Voice or voice conferencing	Voice Signaling	CBR CBR	SVC PVC
Video	Video conferencing	Video Voice Signaling	CBR CBR CBR	SVC SVC PVC
Multimedia point-to-point conversational	Point-point video conferencing with SMDS data connection	Video Data Voice Signaling	CBR VBR CBR CBR	SVC PVC SVC PVC
Multimedia multiparty conversational	Multipoint video conferencing with SMDS data connection	Video Data Voice Signaling	CBR VBR CBR CBR	SVC PVC SVC PVC
LAN interconnect	SMDS	Data	VBR	PVC
BNS-2000 interconnect	BNS-node trunking	Data	VBR	PVC
Circuit emulation	DS1, DS3 circuit	Data	CBR	PVC
SONET/ATM networking	SONET	Data	VBR	PVC

channels from externally connected basic rate interface sets, and provides audio conferencing for those channels over internal audio bridge circuits. The narrowband service module terminates the D channel signaling of the ISDN CPE, and switches the associated B channels through a nonblocking, time-slot interchanging fabric, as directed by the node processor.

Node processor. The node processor provides call processing for the BISDN trial system and OAM&P functions for itself, the narrowband service module, and the video/audio bridge. All switched services requested by customers of the BISDN trial system are managed by the node processor. The node processor receives service requests from ISDN CPE stimulus signaling, and directs connection orders to the appropriate switch fabrics (narrowband service module or ATM network) and service circuits (video/audio bridge) in the network.

Support processor. The support processor provides the OAM&P interface for the general terminal adapters, ATM switch, node processor, narrowband service module, and video/audio bridge. The OAM&P functions supported by the support processor include the graphic user interface, text input parser, spooler, logger, alarm handler, database, audits, download, initialization, state monitor, diagnostic/maintenance, and measurements. The support processor also contains the BISDN connection manager, which is responsible for establishing and tearing down PVCs and SVCs across the general terminal adapters and ATM switch. The connection manager is responsible for VCI assignment, bandwidth management, and connection setup.

Video/audio bridge. The video bridge consists of an analog baseband video conference circuit, an audio conference circuit, a video switch, and four DS3 codecs. The video quad box combines four video images into a single image by placing each input image in a quadrant of the output. Using the feature button of the ISDN CPE to reconfigure the video switch, each conference participant

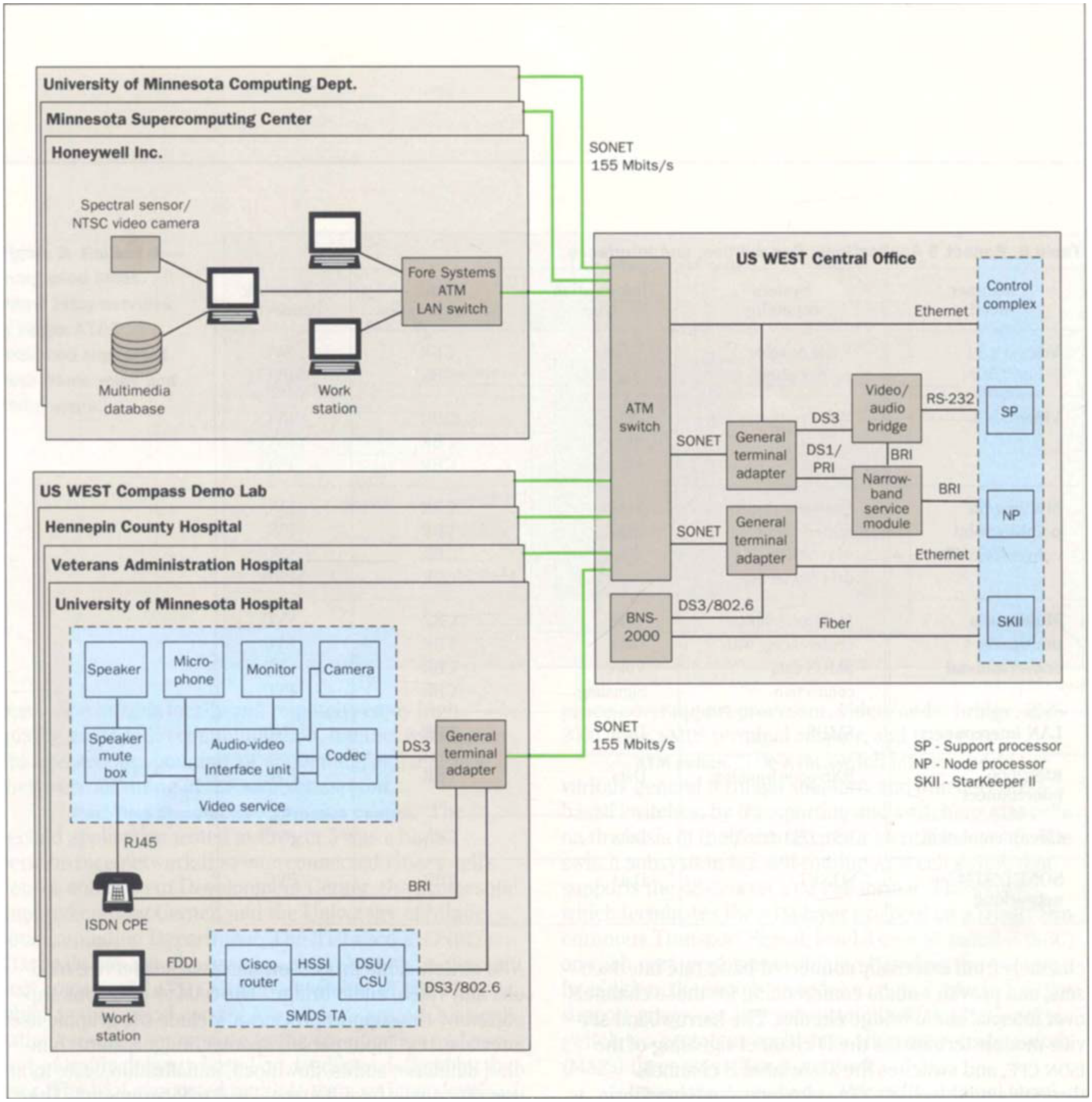


Figure 4. Project 5 — BISDN/ATM trial architecture. This flexible ATM prototype platform simultaneously supported two broadband applications: high-definition distance learning, and real-time manufacturing process control.

can choose to view either the four-quadrant composite image or the full-screen image of any single conference participant. The audio portion, gathered from the conference participants, is mixed together and broadcast to all participants over the audio bridge.

BNS-2000. The BNS–2000 node, also used in Project 4, is a high-speed network switch that supports SMDS data services. The access units in the BNS-2000 node provide standard 802.6 interfaces. The BNS–2000 backplane is designed to operate at 200 Mbits/s, providing high-performance connectionless routing.

SMDS terminal adapter. The SMDS terminal adapter (TA) provides the interface from a customer's Ethernet fiber-distributed data interface LAN to the DS3 802.6-based SMDS link.

ISDN CPE. The AT&T ISDN 7507 Display Terminal set is a signaling end-point that the trial system customers use to make calls and activate features. The number of assigned features and the way they are provisioned are determined by the system administrator, who uses the support processor to assign and remove features.

Trial Evaluation. Because the Project 5 trial is still under way, not all the results are known. However, preliminary feedback from U S WEST and its customers indicates that:

- Video quality was judged to be very good, because DS3 rates were supported in the trial.
- Audio quality was superior to previous trials, because full-duplex, 15-kilohertz audio with echo cancellation was provided.
- Customer documentation (system administrator's guide, and input messages/output messages manual) was well organized and useful.
- The electronic source used to produce paper copies of the customer documentation was also used to provide an on-line, hypertext version on the support processor, allowing the customer immediate access to resolve any questions.
- The graphical user interface, which was built using AT&T's display construction set, provided "point-and-shoot" maintenance and status at the network, site, frame, and circuit pack levels. It also provided access to ORACLE database forms, measurements graphics, and on-line, hypertext documentation. (ORACLE is a registered trademark of Oracle Corporation.) This feature was time-efficient and enjoyable for the craft to use.
- The hardware in the ATM switch, narrowband service module, and general terminal adapters is completely self-provisioned, including drawing the circuit packs in the appropriate locations on the graphical user interface views. This reduces the time required to provision the system.

Conclusions

The information gained and lessons learned from the COMPASS program have been rewarding. Without having to commit to long-term, expensive developments and service offerings, AT&T and U S WEST have been able to explore many potential offerings for broadband services. The decisions to go ahead with development and services have been based on information gained relatively inexpensively and quickly, thus improving the quality of products that AT&T brings to the market, as well as the services that U S WEST offers its customers.

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Trent R. Nanke *is a technical manager in the Broadband and Photonic Switching Department at AT&T Bell Laboratories in Naperville, Illinois. He leads the BISDN Planning and Software Design Group, which plans, develops, and manages broadband application demonstrations and trials. He received B.S. degrees in both electrical engineering and computer science from Iowa State University, Ames, Iowa; and an M.S. degree in electrical engineering from Northwestern University, Evanston, Illinois. He joined AT&T in 1976.*

Barton G. Prieve *is a technical manager in the System Architecture Planning Department at AT&T Bell Laboratories in Denver, Colorado. He plans and coordinates AT&T Network Systems R&D projects with U S WEST. He received a B.A. in mathematics from the University of Wisconsin, Madison; and an M.S. and Ph.D. in electrical engineering and computer science from the University of California, Berkeley. He joined AT&T in 1968.*